

# **ADVANCED TRACK DESIGN**

By

Miodrag Budisa  
Sr. Railroad Engineer  
7030 W. Crain St, Niles, IL, USA  
[Miodrag.Budisa@CTE-Eng.com](mailto:Miodrag.Budisa@CTE-Eng.com)

This paper is an overview of the evolution of advanced track development over the past 30 years – including bottom-up tie/ballast systems and top-down embedded track systems. It is not our purpose to present the findings of any particular theoretical research, or suggest or advertise any particular supplier in the railroad industry, but only address the development of advanced track support systems.

Railroads transformed the geography of the United States in the 19<sup>th</sup> century, supported the industrial expansion in the early 20<sup>th</sup> century, and then temporarily declined in the face of airline and highway competition. To survive, US and Canadian railroads were forced to rationalize their systems, develop more efficient operations, and introduce new services. Today, railroads remain dominant for bulk transportation, provide the backbone of rapidly growing intermodal freight services, and compete successfully with airlines in mid-distance markets. Highway congestion, limited airport capacity, and environmental concerns guarantee a continued role for rail systems in the 21<sup>st</sup> century.

Embedded track systems are one means of lowering railway installation and maintenance costs, thereby contributing to the survivability of this mode of transportation in today's extremely competitive transportation environment.

## **Introduction**

The construction of advanced track support systems for high-speed operations has increased significantly in the past decade and has evolved from very specialized design approaches to state-of-the-art solutions. There are numerous systems, which have been developed, tested and are now in use

The idea of using paving cement or bituminous treated base layers with plain surface and very simple cross-sectional shapes in advanced track support systems comes from road construction technologies. Conventional slip-form pavers and asphalt pavers are used for construction of this type of system. Tolerances for advanced track support system construction compared to road technology are much higher and more restrictive in the design parameters. The higher design speed, up to 200 mph (320 km/h), requires continuous high quality control at the construction site. Discrepancies in longitudinal or transversal roughness or evenness of the treated layer and contact area of the tie or slab respectively will cause deviation from elevation and uneven support.

The use of advanced track support structure systems includes the following advantages:

- Final track geometry is not affected by tolerances in the base support structure.
- Plastic deformation, which causes changes in track geometry; is minimized
- Lateral track buckling potential is reduced;
- Consistent high level of riding comfort is provided;
- Provision of continuous and constant resilient track-properties; and
- Excellent load distribution, thereby reducing the pressure on unconfined soil layers and the subgrade.

Advanced track support systems must be flexible to the influence of various acting forces, which are caused by traffic or environmental conditions.

## **Load distribution**

Load distribution via the track structure to the subgrade is obviously key to the success of any type of track support system. The rail seat load caused by the train action is increased by the effect of centrifugal force and dynamic action. See **FIGURE 1**.

In the United States, calculation of the produced stresses is modeled by the simple beam acting upon an elastic foundation. In Europe, the Zimmerman formula provides a similar, albeit more sophisticated approach, to calculation of the stresses produced by utilizing the longitudinal continuously supported beam model. Both approaches model only the stresses developed by static vertically applied forces. Neither approach considers the complex interaction between wheel and rail or rail and the substructure. In fact, to date no approach accurately models real life conditions. These simple models do not consider torsional stresses, bending stresses, rail fastener stresses due to lateral forces, tie pumping, etc.; nor can their respective values be calculated using these simple models.

As knowledge of the relationships between various components of the track structure increases, computer based modeling such as the Geotrack and Kentrack programs have been developed to quickly evaluate the forces acting between rail, pad/tie plate, ties or slab under different loading conditions.

Advanced track support systems such as slab track have identified the fastener system as key to minimizing vibration and noise control while still providing required elasticity. New hybrids of existing fastener systems have been developed, which obviously must perform as well as existing proven systems.

The following table exhibits the deflections produced at the fastener and in the ballast or slab section under both conventional and slab track supported systems.

Conventional Track Deflection Produced			Slab Track Deflection Produced		
Fastener	.05 - .35 mm	.002 - .014 in.	Fastener	.8 – 1.5 mm	.03 - .06 in.
Ballast	.3 - .7 mm	.01 - .03 in.	Slab	.05 - .2 mm	.002 - .008 in.

It is interesting to note, that in the slab track, the fastener accommodates most of the deflection that occurs in the ballast/subballast section of the conventional track support systems. The fastener must then maintain its elasticity in the horizontal, longitudinal and lateral planes in order to consistently handle the imposed deflections without fatigue failure. Deflection under the slab is minimal, which of course is the desired outcome of slab track. The fastening system then in slab track designs is integral to maintaining the structural integrity of the system.

#### **CURRENT ADVANCED CONVENTIONAL TRACK APPLICATIONS (BOTTOM-UP INSTALLATION)**

Using advanced conventional tie/ballasted track, sufficient load distribution in the transversal direction is achieved by laying ties with large contact areas. The ties must float vertically to guarantee that no negative bending moments are produced. The bending behavior of rail produces negative rail seat loads acting in a negative direction. Loads are small and can further be neutralized using larger cross-sectional ties. Due to the lack of a rigid vertical fixation of the tie as would be present in an asphalt pavement, these forces will cause a low pumping effect between tie and pavement. An intermediate layer of geo-textile can be used to avoid damage in the contact area by dynamic loading and to reduce the effect of pumping.

Roadbed deterioration results from the basic loading principles between the contact points as illustrated above. Modern development in track design found a direct link between the level of pressure and the deterioration of the track. To decrease the pressure on the ballast and subgrade, some designs increase the bearing surface of the tie, some designs use a special H-shaped concrete tie secured to a longitudinal concrete member, or other designs utilize a longitudinal concrete member under each rail connected with a steel pipe.

The following four systems are representative of current advanced bottom-up track support systems:

##### **Wide Tie System**

The Concrete Wide Tie (CWT) system was introduced by the German Railroad in 1995; the objective being to reduce the scope and cost of maintenance work. See **FIGURE 2**.

The dimensions are of the CWT are

- Width - 22.4 inches (57 cm),
- Length - 94.5 inches (2.40m)
- Tie spacing - 24 inches (60 cm).

The tie is constructed of B70 (10,150 PSI) concrete. Axle loading of 24 tons results in a surface pressure of 28.5 lb/inch<sup>2</sup> (2 kg/cm<sup>2</sup>). (Conventional ties subjected to the same axle load results in a surface pressure of 45 to 52.6 lb/inch<sup>2</sup> (3.16 to 3.7 kg/cm<sup>2</sup>). The wide tie system utilizes both pre-stressed and non pre-stressed reinforcement. A foam insert is placed between supports.

Tamping is performed only at the end of the tie because of the close tie spacing. A tamping machine was modified with the tamping unit turned 90 degrees and installed on a frame located over the end of each tie. An inspection after 50 MGT in a 37°44" curve with a maximum speed of 100 mph (160 km/h), (radius R=2650 m), revealed the track quality index for positional stability ranged from good to very good. A variety of measurements yielded the following conclusions:

- High track positional stability achieved
- Improved resistance to transverse displacement (Measurements performed with a tie using a 60mm camber plate have been improved by 15% over conventional ballasted track)
- Very low structure-borne noise
- Reduced surface pressure between tie and ballast (36% reduction) ( Technical University of Munich)

### **Frame Tie System**

The double H-shaped concrete tie with “longitudinal concrete beam” is designed to increase the bearing surface and reduce the pressure on the ballast. This configuration creates very high stiffness; thereby providing alignment stability and increased buckling resistance. This system has been successfully used by the Austrian National Railway for the past 15 years. See **FIGURE 3**.

### **Ladder Tie System**

Ladder Ties are another on-going development of advanced ballast track support systems. They consist of 36 foot long pre-stressed longitudinal concrete members connected by lateral steel tubes, much like a ladder. The rails are supported continuously on the concrete members, which distribute the load in the longitudinal direction; thereby, reducing the need for ballast maintenance. See **FIGURE 4**.

### **Y Steel Tie System**

The Y steel tie, See **FIGURE 5**, has been designed to provide better positional stability and cost savings. The system is suitable for new track construction, renewal and expansion and can be used for all types of sections -, normal, wide or narrow on ballast or on slab track. The Y-tie form is created from two S-shaped, wide flange supports and two straight girder sections with the same profile. The connection is achieved using two lower and six upper cross brackets, which are welded to the flanges. The Y-tie also has three paired rail supports with central rail fastening. The support profile has a double-T shape with a large flange width and a low construction height of 4 inches. The Y shape together with the secondary support allows the rail to be supported in two places, i.e., the “double support”. The advantages of the Y-tie system include:

- Above-average lifespan,
- Excellent positional stability,
- Reduction by 50% of number of ties required,
- Approximately 30% less ballast.

## **CURRENT EMBEDDED TRACK SYSTEMS (TOP-DOWN INSTALLATION)**

On the basis of design and construction principles, embedded track systems in use today generally fall within one of the following groupings: See **FIGURE 6**.

1. Direct fixation on continuously reinforced concrete pavement such as the Shinkansen in Japan.
2. Prestressed slab connected to a treated base of asphalt or concrete using sealant mortar to bind base and slab such as the Bögl System in Germany: See **FIGURE 7** and OBB Porr System in Austria.
3. Pre-cast concrete tie panels embedded in concrete, which are supported by a monolithic concrete reinforced pavement on a treated base course, such as the Edilon System as used in Holland and France:
4. Twin-concrete block ties connected by a horizontal steel member. The complete system is embedded in an asphaltic-concrete material and supported by a treated base course such as the Rheda System in Germany: See **FIGURE 8**.
5. Twin-concrete blocks embedded to a continuously reinforced concrete pavement (CRCP), See **FIGURE 9**. such as the Sonnevile LVT System in the United States and the Chunnel Tunnel under the English Channel or Zueblin System in Germany.

6. Embedded specialized rail section in concrete slab such as the Balfour Beatty.: See **FIGURE 10**. The Balfour Beatty, has been tested under full traffic conditions in Medina, Spain and will be utilized in the New York 5<sup>th</sup> Avenue project.

### **Embedded Track Construction Examples and Description**

A representative sampling of the more common top-down embedded track systems includes the following:

**Direct Fixation (Shinkansen Line):** The Shinkansen System is a continuously coupled precast concrete slab

- Length - 16.1 ft(4.93m)
- Width - 7.3 ft (2.22m)
- Depth - 7.5 in (0.19m) on a hydraulically stabilized concrete sub-layer.

The slabs are connected by the use of cylindrical bollards (keys) located at the slab ends, which prevents lateral and longitudinal movement. Continuous Welded Rail (CWR) strings up to 600' (200m) in length are brought to the site and are loaded onto trolleys. The trolleys run on temporary rails laid wider than the track gauge. These temporary rails follow the pre-cast slabs as they are being installed. They are also used for placement of asphaltic-concrete mortar under the slab in the adjacent track. See **FIGURE 11**. for installation process.

**Bögl System:** This system uses a longitudinal continuously coupled precast plate on a hydraulically stabilized subbase. This type of embedded track system was derived from the positive experiences produced on the test track near Karlsfeld, Germany beginning in 1977. The 8 inch (20 cm) thick, 20 feet (6.45 m) long, and 6.8 feet (2.8 m) wide slab uses B55 (8000 PSI) steel fibre reinforced concrete. See **FIGURE 12**. As in concrete ties, the steel is prestressed in the lateral direction. In the longitudinal direction, the precast plates are coupled to each other with traditional reinforcement. The butt joints between the slabs are prestressed. Once the precast slabs are placed on the treated roadbed (concrete or asphalt layer) and longitudinal reinforcement is installed, the rail is ready to be threaded into position. Spindle devices are mounted to the outside of the slabs to allow exact adjustment in height and cross level positioning. Once the precast slabs have been adjusted, a grout mortar is used to fill the void at the edge between the treated roadbed and the slab before a bituminous cement mortar is injected underneath the precast slab. After the mortar hardens, the extended nut between the slabs is tightened to frictional resistance to achieve pre-stress forces across the joint. The injected bituminous cement mortar and the treated roadbed prevent movement in the longitudinal and lateral directions.

**Edilon System:** The Edilon Corkelast Rail System uses traditional slab track layer design with a frost protection layer, a hydraulically-bonded layer and a concrete support slab. The concrete support slab is formed in-place continuously without construction joints and is 15.7 inches (40 cm) in height and 6.7 feet (2.04m) in width. The rail is suspended or “floated” into a longitudinal pocket and the Corkelast (special elastomeric cementitious-asphalt material) is poured around it. The trough set in the concrete bed determines the rail height, alignment, track gauge and inclination. Since the Corkelast is in liquid form when applied, it is sufficiently flexible to allow manual installation of the rail and required adjustment. Horizontal and vertical rail forces are absorbed by the elastic, two-component mass and the cork underpad. See **FIGURE 13**.

**Sonneville Low Vibration Track (LVT) USA:** After completion of surveying, the pre-assembled LVT blocks are transported and distributed along with single rails or CWR strings along the alignment. Once the rail is threaded over the LVT blocks on rollers, it is lowered onto the previously positioned rail pads and secured in place with the rail fastenings. The rail ends are connected with temporary joint bars or permanent welds. The blocks are secured transversally with temporary gauge rods. The track now resting below its final elevation can immediately be used for work trains to advance the trackwork. Vertical and lateral adjustment is applied via the temporary gauge rods. Once the geometry is checked, the site is ready for concrete installation. See **FIGURE 14**.

**Rheda System:** The construction work for the new High Speed Rail (HSR) between Köln and Frankfurt, Germany is underway on Europe’s longest building site using the Rheda Rigid Track System. The track framework is made out of ties, which are fully embedded in Class B35 (5000 PSI) concrete. Concrete is distributed and compacted to create a reinforced trough. The percentage of reinforcement is 0.8 to 0.9 to

control shrinkage cracking during curing. The outside trough shoulder does not contain reinforcement but must still remain within the permissible position and height tolerances. Class B35 (5000 PSI) concrete (0.27 CY/linear ft.) is distributed and compacted for each foot of Rheda trough. in precise accordance with the stipulated trough profile. In one Rheda curve, the paving profile maintains a maximum cross pitch of 12%, which equals a superelevation of 6 ¾ inch (170 mm) from center to center of railhead. During construction, the slipform paver progresses at a paving speed of 3 feet/minute. B35 (5000 PSI) concrete is fed to the slipform paver from a ready-mix truck via a side loading conveyor belt, which is directly in front of the spreader auger. Crews place the rigid rail track using a track wire-free guidance system. The slip paver is continuously guided without the need for a track wire by means of two target-tracking total stations. A third instrument checks placement measurement results at regular intervals and facilitates the location of the theodolites relative to the proposed centerline. Measurements from the two total stations are continuously fed back to the slipform paver on-board computer by modem. The information passed to the machine's control unit by a two-axle X-Y slope sensor, mounted on the slipform paver, enables the position of the machine to be indicated accurately at all times in a digital topo 3D model. This rectifies any twisting, which may affect the placement planarity. See **FIGURE 15**.

**Balfour Beatty System:** features a low height reinforced concrete track slab incorporating slots for receiving a rail subsystem. The new top-down application by Balfour Beatty takes a different approach. See **FIGURE 16**. The rail subsystem consists of a glass reinforced plastic shell housing a resilient elastomeric pad. A specialty designed symmetrical rail section is fitted within the housing. The subsystem is correctly aligned in the slot and grouted in to the final position. A seal is added to complete the system. The result is a track that is continuously supported both horizontally and vertically. Unlike conventional systems, it will not distort under load. The previous mentioned top-down applications of embedded slab track require accurately positioning the rails. When the rails are finally positioned, concrete is poured around the rail to fix them into position.

New symmetrical rail (not T-shaped) 5 ½ x 2 ¾ inch (139.7x69.85 mm) and 149 lb/yd (74 kg/m) is installed into the pre-formed steel and steel fibre reinforced concrete slab. The rails are positioned independently of each other to line, level, rail cant and gauge to a high level of accuracy ±0.03 in ( ± 1 mm). The system is secured in place in the reinforced concrete slab by means of a polyurethane polymer pad and glass-reinforced plastic shell, which fits into longitudinal pockets cast into the concrete slab to accept the rail. Special alignment support has been designed to be easily used by two laborers without the need for additional lifting equipment. Lifting support is arranged to secure and fit the rail into the required rail cant of typically 1:10, 1:20, 1:40 or vertically. The system allows the reinforced concrete slab installation process to proceed in advance of the track laying process, thus reducing interference between each activity during construction. Unlike most other embedded track systems, this application of the reinforced concrete slab can be constructed by slip forming in one pour. Only a thin layer of concrete grout is required to fix the rail. This results in:

- Lower height in tunnels, where the top of rail to bottom of concrete reinforced slab height can be as low as 10.5 inch (270 mm)
- Reduction in dead load for viaduct and bridge.

### Life Cycle Cost analyses

A representative summary of cost for the superstructure, excluding the concrete slab, for various systems is as follows in USD/yd.

Cost estimate	Construction	Annual Cost
▪ Conventional ballasted track	USD 1,037	USD 125
▪ Wide Tie	USD 1,195	USD 102
▪ Sinkansen	USD 1,345	USD 114
▪ Edilon	USD 1,315	USD 114
▪ Rheda	USD 1,315	USD 114
▪ Balfour Beatty	USD 1,400	USD 91
▪ Slab track ERS Integrated	USD 943	USD 91

It is evident from the above that advanced track support system construction and maintenance costs are competitive with conventional ballasted track applications.

## **CONCLUSION**

A cost effective infrastructure is a key factor for the survival and further success of the modern railway system. Advanced track support systems, both bottom-up and top-down construction, are a proven technology capable of carrying modern high-speed rail or heavy haul systems well into the 21<sup>st</sup> Century. As new placement technologies are discovered along with shortened available maintenance windows, the use of advanced track support systems will become ever more economically viable compared to conventional ballasted track.

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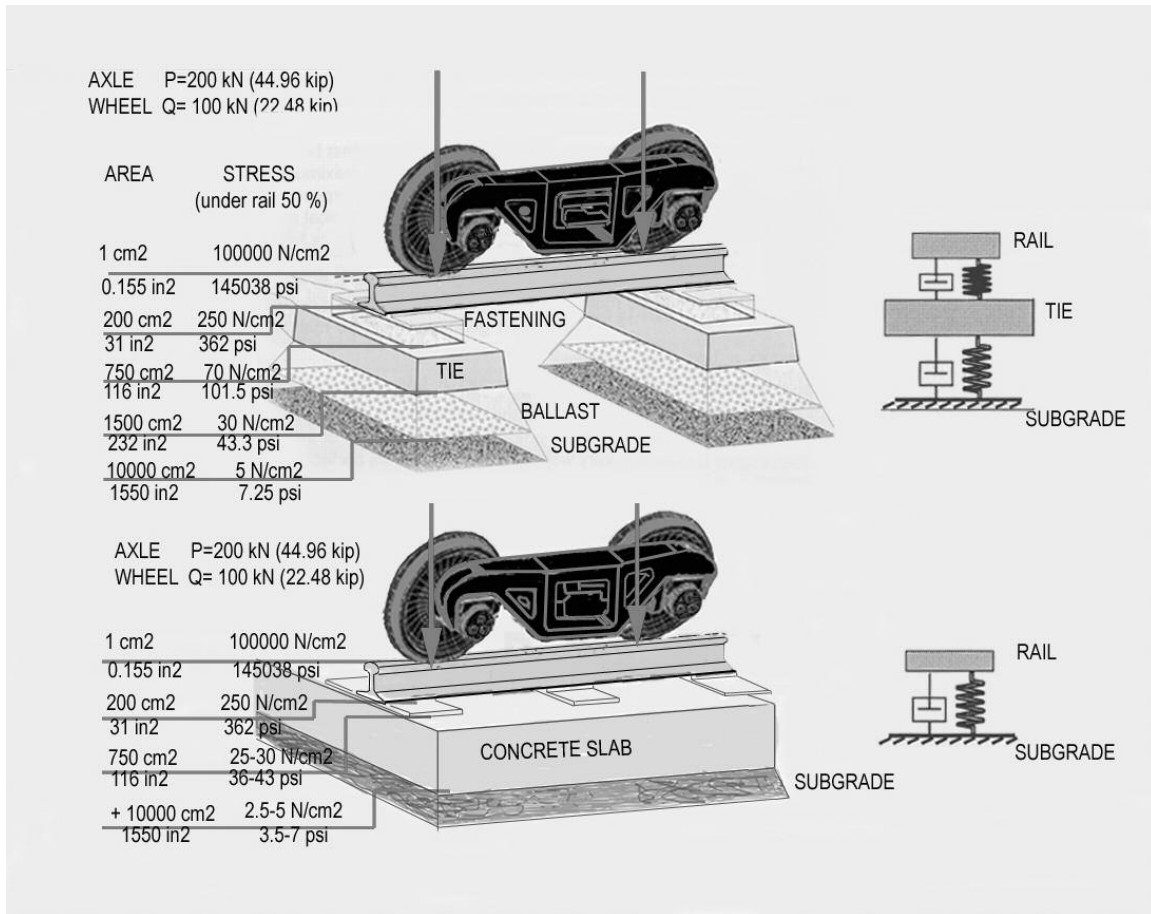
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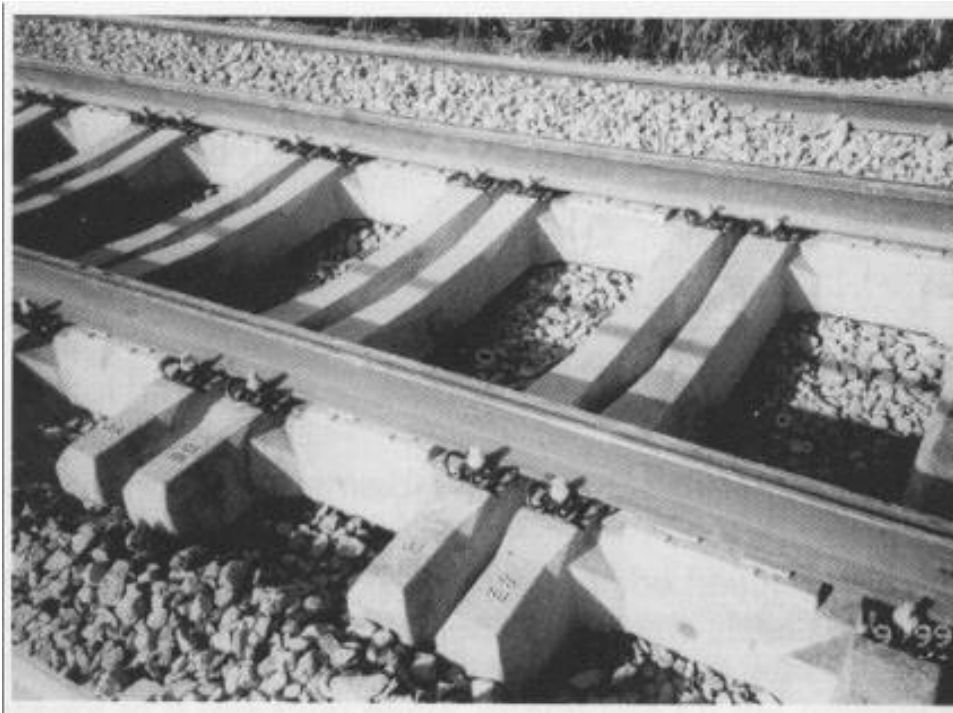
**FIGURE 1** Loading distribution



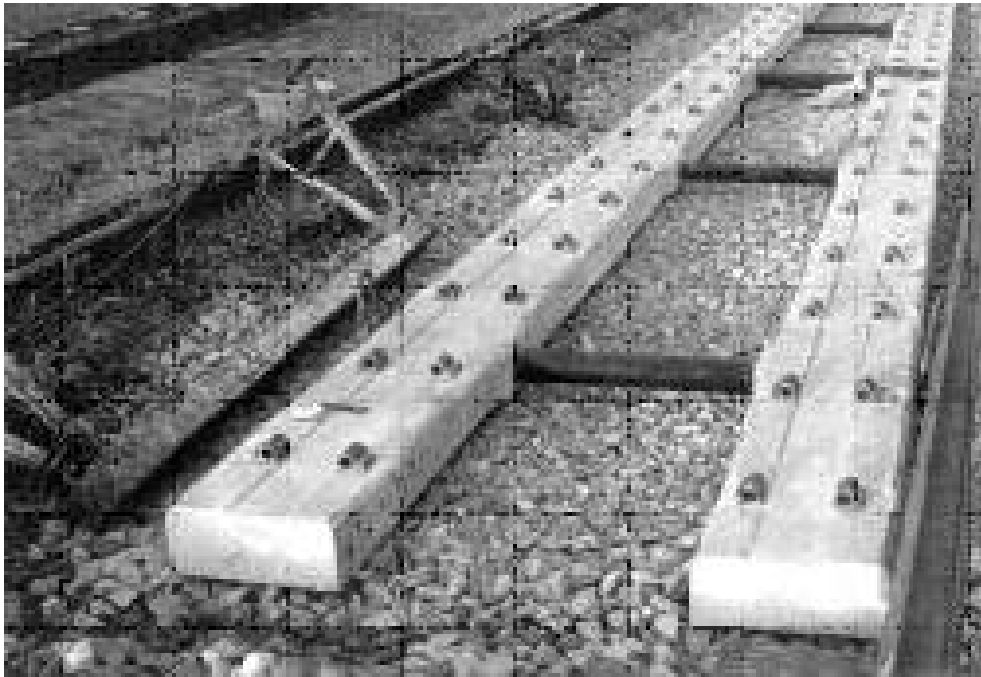
**FIGURE 2** Wide Tie System



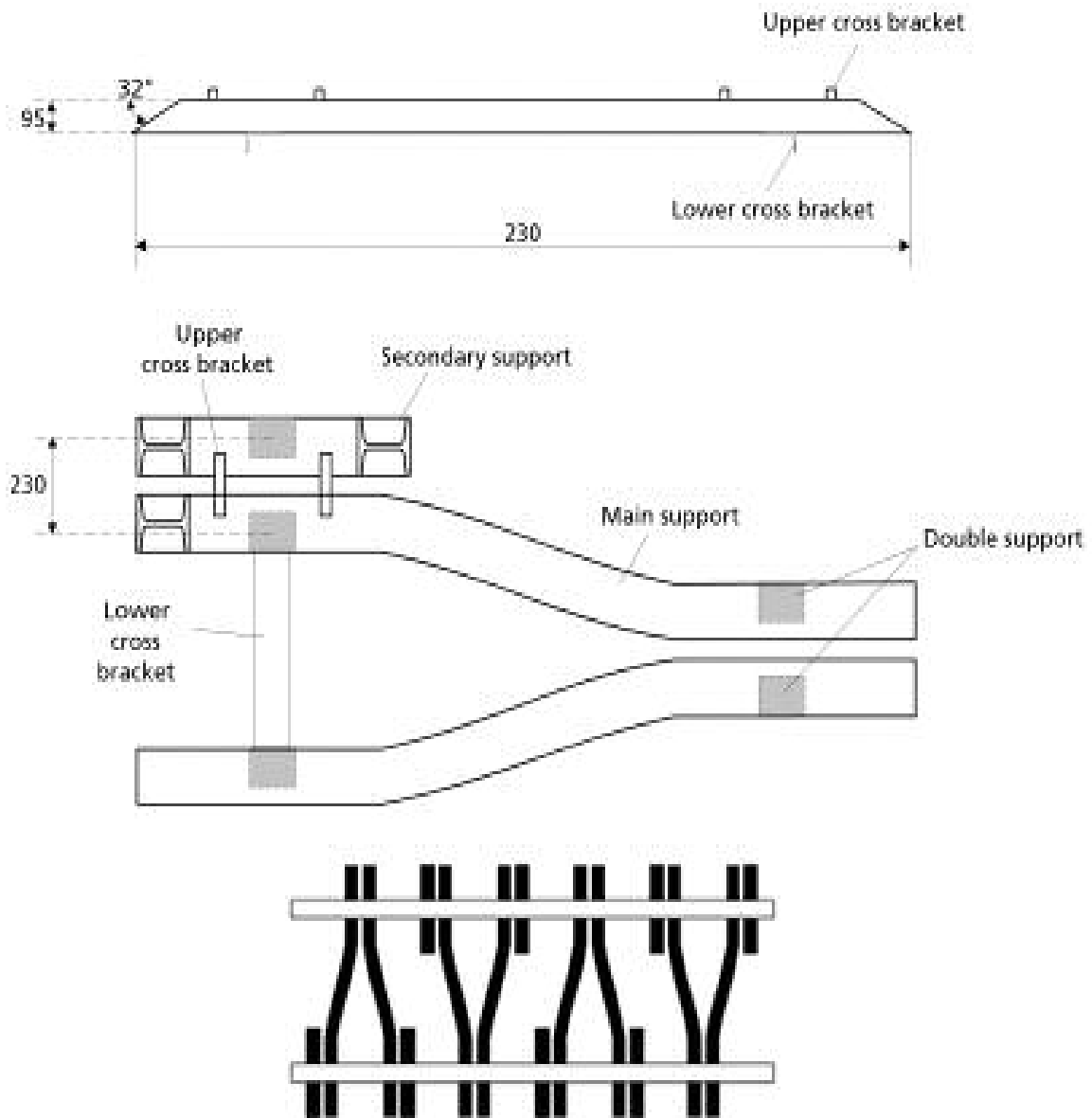
**FIGURE 3**      Frame Tie System



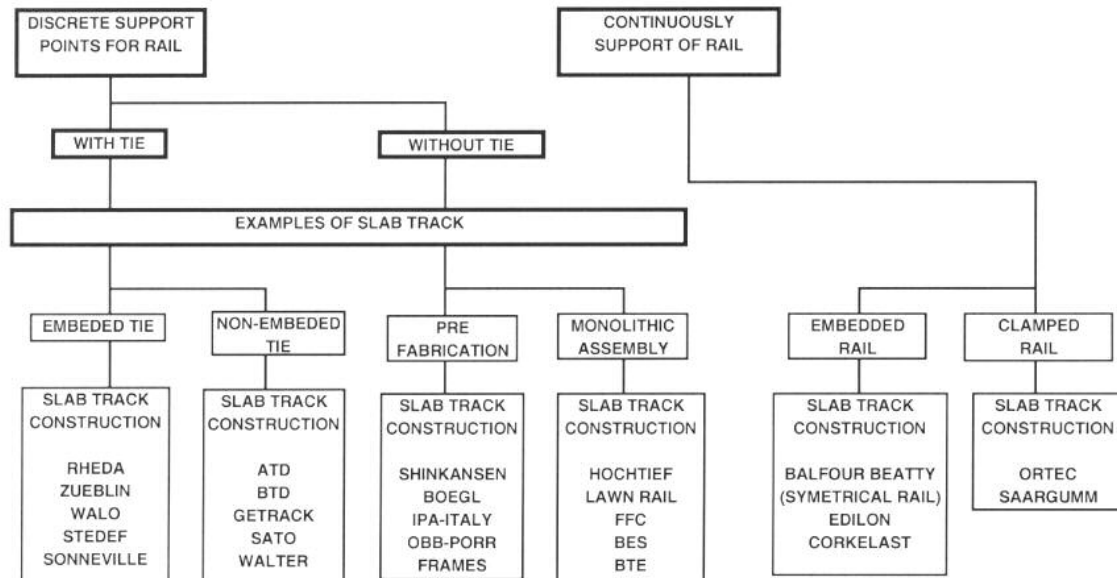
**FIGURE 4** Ladder Tie System



**FIGURE 5** Y Steel Tie System

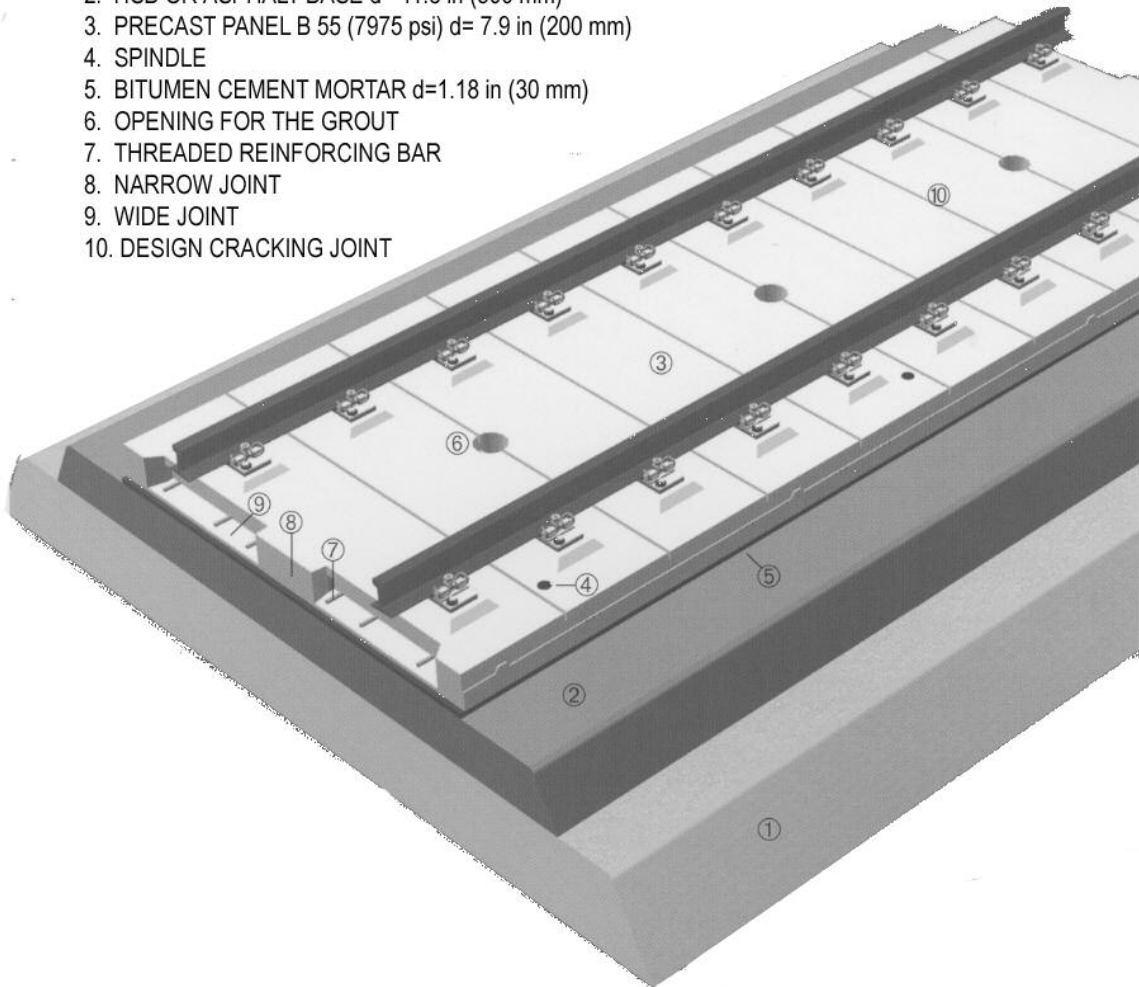


**FIGURE 6** Classification of Types of Advanced Track Construction

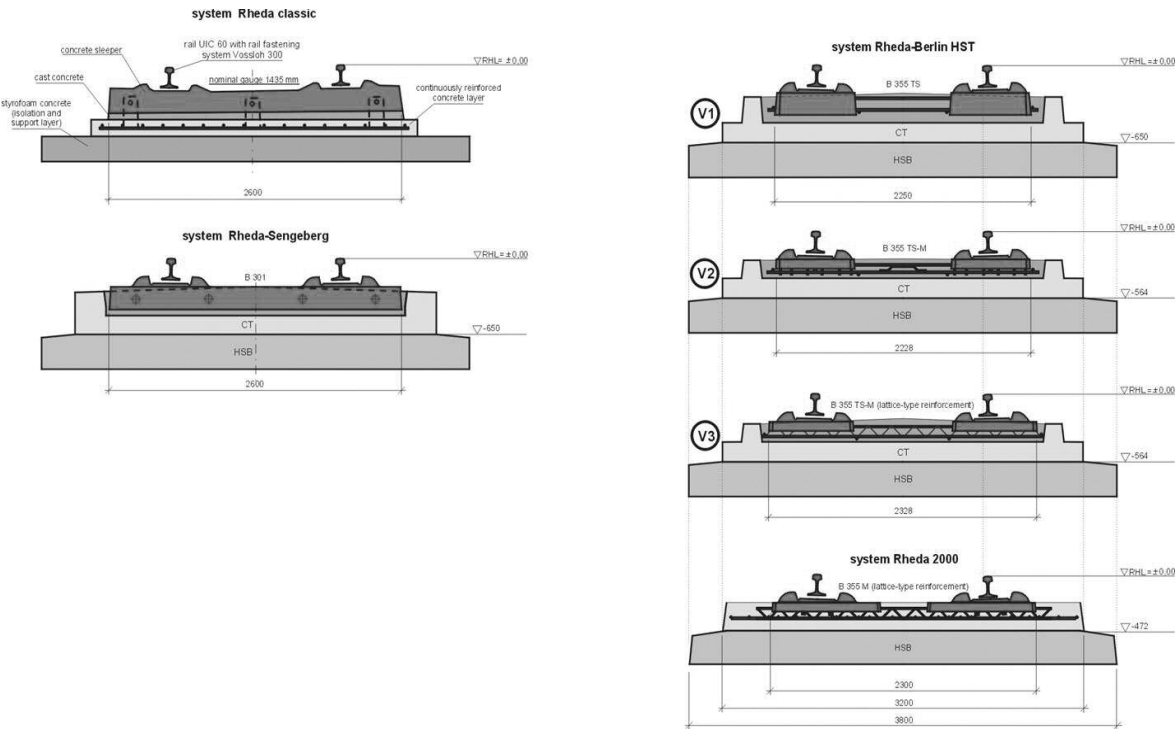


**FIGURE 7**      Boegl System

1. FROST PROTECTION LAYER
2. HSB OR ASPHALT BASE d= 11.8 in (300 mm)
3. PRECAST PANEL B 55 (7975 psi) d= 7.9 in (200 mm)
4. SPINDLE
5. BITUMEN CEMENT MORTAR d=1.18 in (30 mm)
6. OPENING FOR THE GROUT
7. THREADED REINFORCING BAR
8. NARROW JOINT
9. WIDE JOINT
10. DESIGN CRACKING JOINT



**FIGURE 8** Rheda System

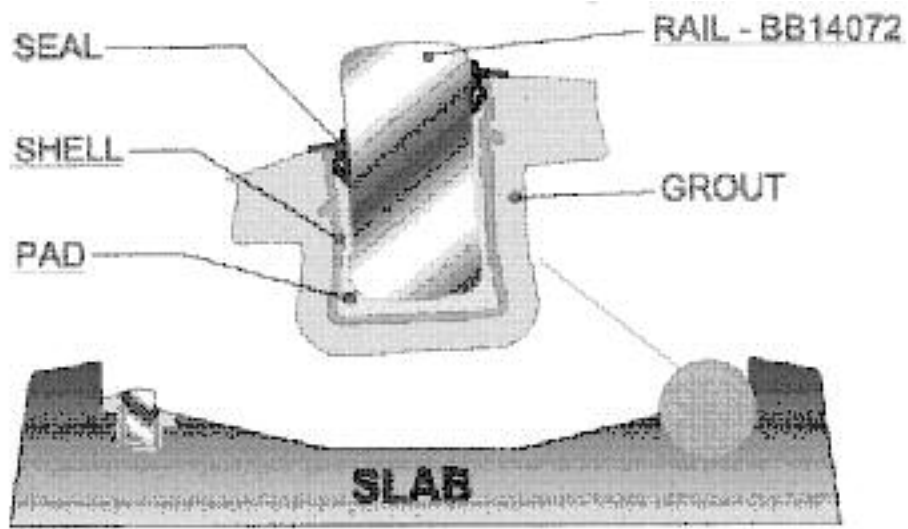




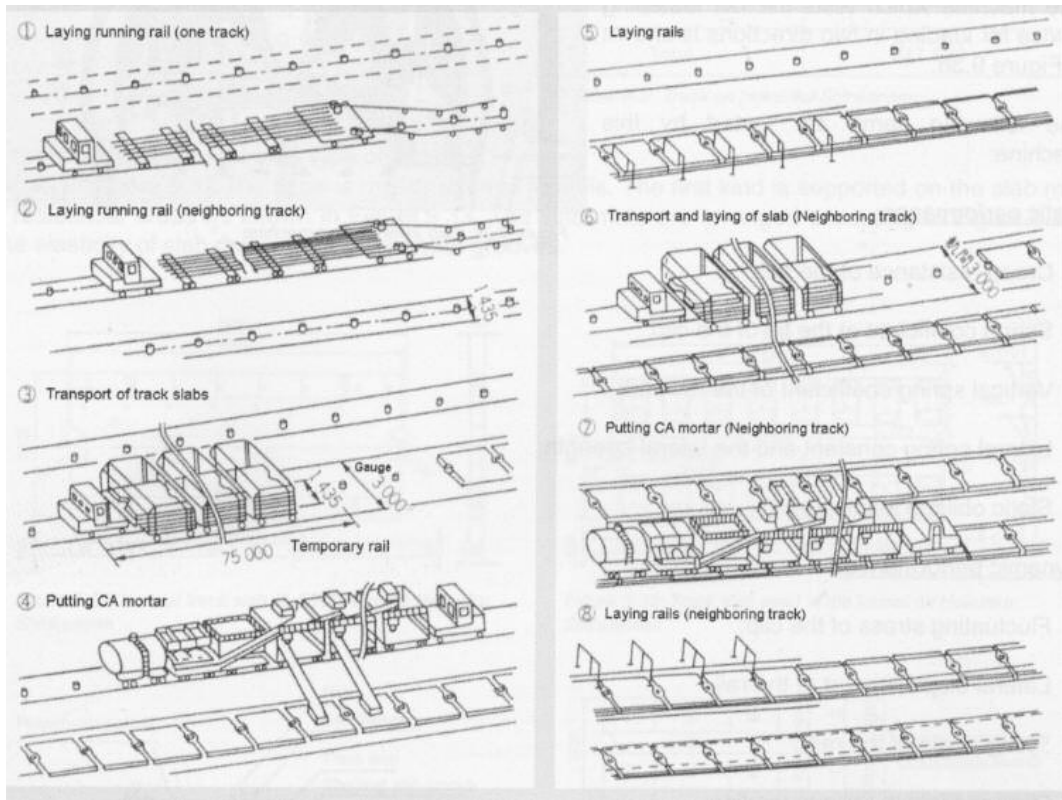
**FIGURE 9**      Zueblin System



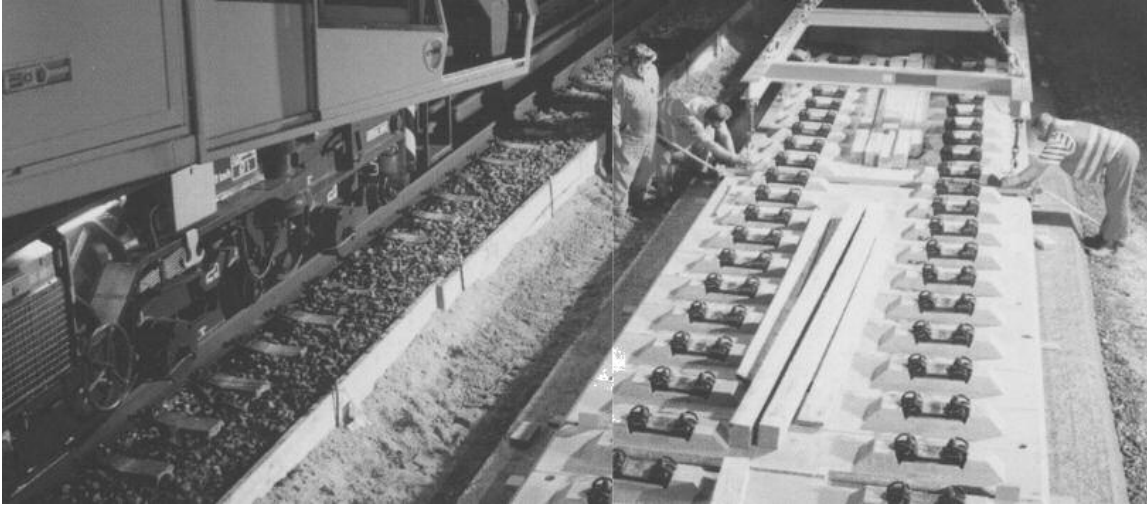
**FIGURE 10** Balfour Beatty System



**FIGURE 11** Shinkansen Instalation Methode



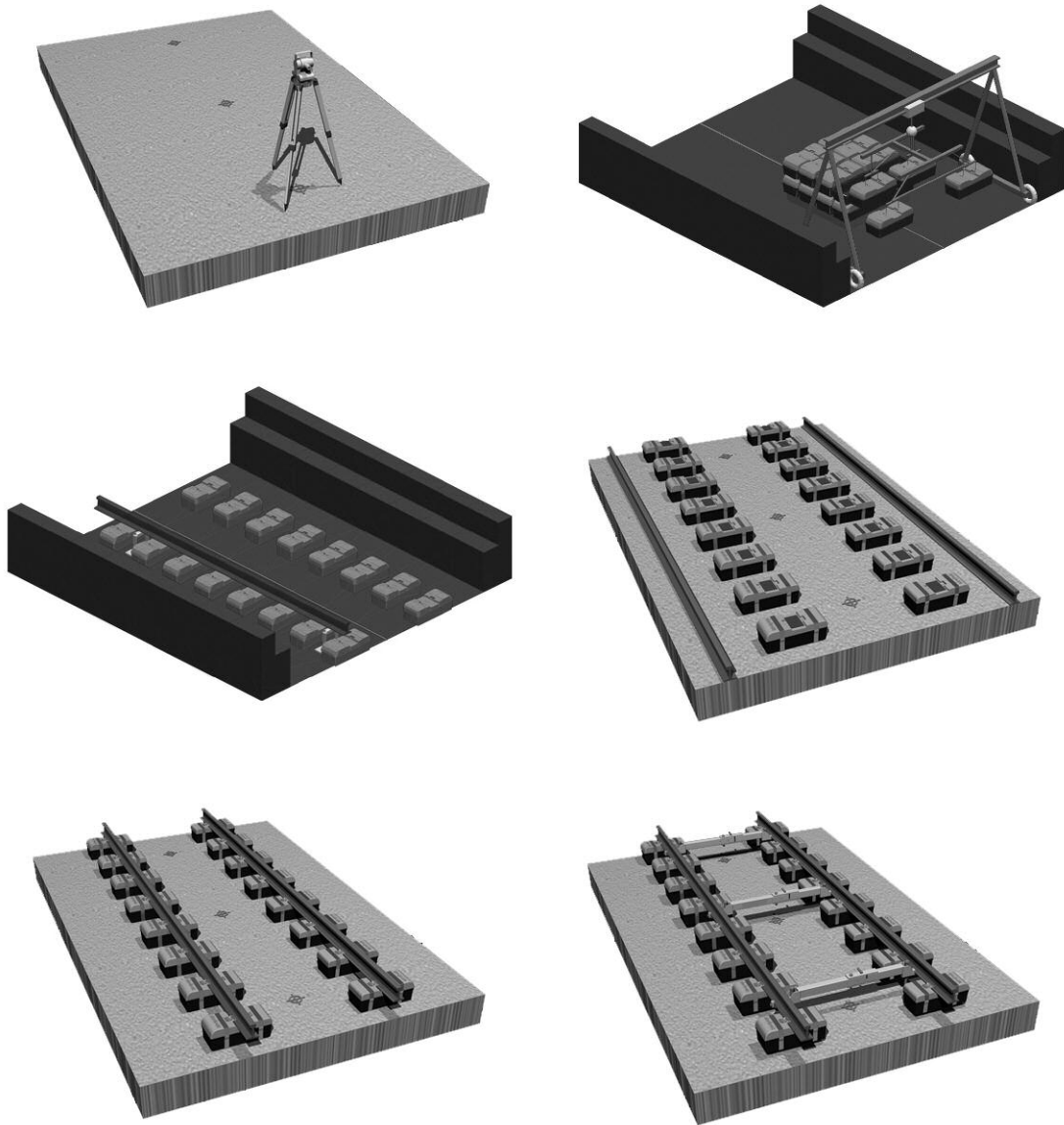
**FIGURE 12** Bögl Instalation Methode



**FIGURE 13** Edilon Instalation Methode



**FIGURE 14** Sonneville Instalation Methode



**FIGURE 15** Rheda Instalation Methode



**FIGURE 16** Balfour Beatty Installation Methode

